

No anticipation–no action: the role of anticipation in action and perception

Wilfried Kunde · Katrin Elsner · Andrea Kiesel

Received: 6 December 2006 / Revised: 5 February 2007 / Accepted: 8 February 2007 / Published online: 6 March 2007
© Marta Olivetti Belardinelli and Springer-Verlag 2007

Abstract This paper reviews psychophysical evidence for the existence and the nature of two types of anticipation in goal-oriented action. The first one relates to attained changes of the perceptual world, thus to action goals. These anticipations determine appropriate motor output. We argue that goal codes do not only serve as a reference unit, against which currently produced behavioral effects are compared. Rather voluntary actions appear to be planned literally in terms of intended behavioral effects. The second type of anticipation relates to the environmental conditions that have to be met to bring an intended effect into being. These anticipations serve to trigger selected actions, when appropriate execution conditions are encountered. Altogether, the behavioral evidence portrays a remarkable automaticity of goal-oriented action. Once a goal exists (wherever it might come from), corresponding efferent output is generated and executed under appropriate conditions.

Introduction

Evolution has brought about different ways to enable organisms to behave adaptively. One way is to furnish

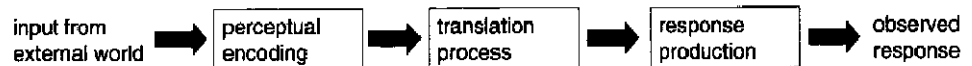
organisms with a fixed set of behavioral responses to a set of relevant stimuli, so that certain stimuli elicit certain predetermined responses automatically (Tinbergen 1951). Frogs might behave this way when they catch a passing fly by fulgurously protruding their tongue. It is fair to say that cognitive psychology has at times portrayed a picture of human behavior that appears somehow frog-like. From the days of Donders (1868), it has become common practice to conceptualize action control as a chain of processing steps between certain stimulus input and certain motor output (Neisser 1967; Sanders 1980; Sternberg 1969, cf. Fig. 1). In this model, behavior appears as mere reaction to stimulation, in a sense, frog-like. And admittedly, this model seems to describe quite well the sequence of events in the favorite situation of cognitive psychologists, the choice reaction task—a stimulus is presented, let us say the letter “A,” some processing occurs, and a corresponding motor response, let us say a left key press, is eventually emitted. This approach has accumulated a number of important findings and methods that have become standard knowledge of cognitive psychology (Sanders 1998).

Yet, this approach is not unproblematic. The main problem is not so much the simplicity of the studied behavior (key pressing in this case). At any rate it is fair to simplify matters when we investigate human behavior in the lab. The main problem is that it inadequately describes human behavior as stimulus-driven. Human behavior depends much less on current stimulation than on to-be-attained goals, be these goals complex, such as writing a scientific paper, or simple such as typing the letter ‘I’ on a computer keyboard. Thus, the cause of our actions lies not so much in the present (in the stimulus), but in the future (in the goal). This applies to behavior in general and to choice reaction tasks in particular. Nothing would happen after a stimulus if the actor did not have the goal to produce

W. Kunde (✉) · K. Elsner
Department of Psychology,
Martin-Luther-University of Halle-Wittenberg,
06099 Halle (Saale), Germany
e-mail: w.kunde@psych.uni-halle.de

A. Kiesel
Department of Psychology,
Julius-Maximilians-University,
Roentgenring 11, 97070 Wuerzburg, Germany

Fig. 1 A linear stage model of information processing



the required response, that is, if (s) he did not have the intention to see, feel and possibly hear the re-afferences of the required motor pattern. Thus, the letter “A” in a choice reaction experiment is in fact nothing more than a request to the participant to produce the sensory consequences that a left key press normally produces. In other words, even a response as simple as a key press is a goal-oriented action (Hommel et al. 2001; Prinz 1997; 1998). The important step forward for such a perspective is that it focuses on the processes that occur prior to, and independent of, certain stimulation rather than on the processes that intervene between stimulus and response (Fig. 1).

The relevance of such preparatory processes has not gone unrecognized in cognitive psychology. Monsell (1996) noted that the ability of participants to transfer a verbal instruction into accurate behavior in a choice reaction experiment is actually one of the most challenging puzzles in cognitive psychology. The preparatory processes assumed to mediate this ability have often been described as task set implementation (Monsell 2003), and the assumption is that task sets alter top-down the way stimulus input is transformed into motor output (Braver and Barch 2006; Dosenbach et al. 2006). In the following, we want to discuss the role of anticipation in such task sets, and in goal-oriented action in general.

There are two sorts of anticipation that we have to consider here (Hoffmann 1993, 2003; Butz and Hoffmann 2002). The first anticipation relates to the intended effect of the action and thus the goal (Fig. 2). Obviously some representation of an intended effect has to precede the action itself, otherwise it would be impossible to specify a goal-satisfying motor pattern at all. These anticipatory codes can be termed *effect anticipations*. For example, to pick strawberries, some representation of the hand touching a strawberry seems necessary to select an appropriate grasping movement. In a choice reaction experiment, some representation of a key press (what it feels like, looks like, sounds like and so on) appears necessary to intentionally select the desired key press. Obviously, these are examples of simple actions that might be carried out to serve superordinate goals. Strawberries might be picked to still one’s hunger, and a key in a choice reaction experiment might be pressed to receive a course credit. Thus, complex actions are typically split into a couple of sequentially organized subgoals. Still, even complex goals must eventually be realized by concrete motor actions. It seems appropriate to start research with such simple actions, and therefore this is the type of actions the present review is concerned with.

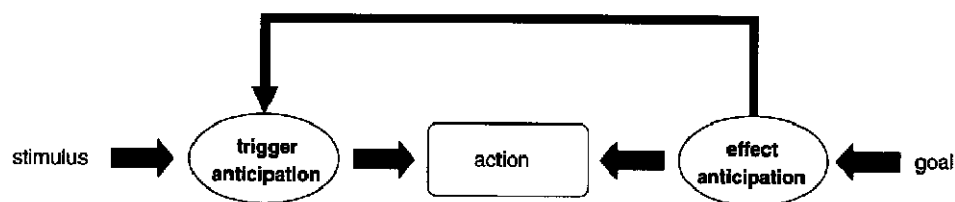
A second type of anticipation relates to the environmental conditions that signal a good opportunity to successfully produce the desired effect. These might be called *start anticipations* because the occurrence of a favorable environmental condition should immediately prompt the execution of the prepared goal-oriented action. For example, to pick strawberries, it would be useless to initiate a grasping movement unless a strawberry and its location in the shrub have been detected. If a strawberry were present, however, it would be good to instantaneously grasp it, so that it is not lost by some unfortunate event, such as an outdoing conspecific.

Anticipatory effect codes

To intentionally produce a goal, we need to know and predict the consequences of our actions. Otherwise, we could only move and hope that our motor output produces the desired effect accidentally. Consequently, representations of action effects are incorporated in several models of motor control. For example, closed loop theory assumes that movement execution prompts the creation of an anticipatory references signal to which perceptually available movement feedback is compared in order to allow corrective movements (Adams 1971). In fast movements, the reference is not compared to actually available, but to anticipated, feedback during movement execution—thus implying a feedforward of movement consequences (Desmurget and Grafton 2000). These models ascribe to anticipated feedback (mostly spatial information about a moving limb) an important role in the control of movement execution.

Yet, there is another approach that ascribes to effect anticipation an even more fundamental role for action control, on which we want to focus in the following. The idea is that motor patterns become automatically and intimately associated with their internal and external sensory consequences. Lifting a hand, for example, which might at first occur accidentally in the newborn, becomes linked to the proprioceptive, visual, and possibly auditory consequences of the moving limb. These action-effect links can be used in both ways, to predict the sensory consequences when the movement is known and, more importantly, to recruit the required movement when a certain effect is intended (similar to feedforward and inverse models in computational modeling; Wolpert et al. 2002). This approach has been termed *ideo-motor principle* and can be traced back to authors of the nineteenth century (Harleß

Fig. 2 Trigger anticipation and effect anticipation in action control



1861; James 1890; Lotze 1852, for an historical review cf. Stock and Stock 2004). The crucial assumption of the ideomotor approach, which distinguishes it from other models of action control, is that there is no other cognitive representation of a body movement than its sensory consequences (Hommel 1996). Thus, there exists no efferent representation, such as a motor command or motor parameter that would be directly accessible to the actor. Consequently, the only way to intentionally recruit a body movement is by recollecting codes of the movement's re-appearances (Greenwald 1970; Hommel et al. 2001; Prinz 1987).

This is a radical view that, admittedly, sounds a bit mysterious. Can it really be that merely "thinking" about an action's consequences, as James (1890) termed it, has the power to activate the action itself? There is now a considerable body of evidence that is clearly confirmative. First of all, there are all kinds of findings showing that the mere observation of a potential action effect has the power to induce the motor patterns that eventually would cause these observed effects. One of the most immediate effects of motor output is the observable movement of the body itself. For example, contracting muscles in the forearm might result in an upward movement of a finger. In the first place, this movement is visible to the actor. Yet, it is also visible to other observers and resembles to some extent the visual effects of an observer's own finger movements. Interestingly, in such situations, the observation of a person's movement does to some extent induce the same movement in the observer, a phenomenon known as imitation (Brass et al. 2001; Stürmer et al. 2000). To the extent that the perceived consequences of a model's movements resemble those of the perceiver, imitation can be construed as evidence for action priming by effect perception.¹ Similar action priming occurs with more distal action effects in experts of a certain domain. For example, in pianists the perception of a certain chord induces the finger movements

necessary to play the corresponding chord (Drost et al. 2005). In expert typists, the perception of a certain letter on a screen primes the typing action necessary to produce this letter (Rieger 2004). But even a very limited amount of practice of a few experimental trials seems to suffice to create similar phenomena. For example, after having produced a high tone with a left-hand key press, the presentation of a high tone primes a left-hand key press (Elsner and Hommel 2001). Interestingly, after such action effect links have been acquired, even the subliminal presentation of an action effect primes its corresponding action (Kunde 2004). Thus, whereas the intention to produce a certain goal might afford consciousness, the ensuing processes that activate corresponding motor processes do not.

Although these studies show that motor-effect links become acquired quickly and can be primed by stimulating corresponding effect-codes, they do not yet prove that anticipatory effect codes actually play a role when it comes to intentionally selecting an action. Yet, at the least, indirect evidence for such a role comes from studies, which show that the speed of action generation is affected by properties of the subsequently ensuing action effects. For example, motor actions are emitted more quickly when they produce compatible rather than incompatible action effects, such that pressing a left key is easier when the key lights a left rather than a right lamp, or pressing a key softly is easier when this produces a quiet rather than a loud tone (Kunde 2001) (Fig. 3). Action-effect compatibility plays a role even with very simple and well-practiced tools such as first-class levers (cf. Fig. 3 bottom; Kunde et al. 2007). These effects can be explained by mutual priming of the actions' proximal (e.g., tactile) and distal (e.g., auditory) effect codes. The level of activation of effect representations, that is necessary to elicit motor output, is reached earlier when proximal and distal effects are congruent rather than incongruent (Kunde et al. 2004). Obviously, when the generation of an action is affected by effects that occur after the action is initiated, there must be processes that bring these effects to mind before the action actually ensues. In other words, action generation involves, and is possibly mediated by, the anticipation of the actions' consequences, which is in essence what ideomotor theory implies.

Based on such influences of to-be-produced action effects on action production, a couple of issues regarding the

¹ Imitation has also been reported when observed and imitated movements cannot be directly linked via the same perceptual channel. For example, newborns imitate the seen facial expressions of adults, although the babies have not acquired a visual representation of their own facial expressions (Meltzoff and Moore 1977). This has been explained by the assumption of inborn supramodal representations of certain actions' consequences (cf. Heyes 2001 for further discussion of this issue).

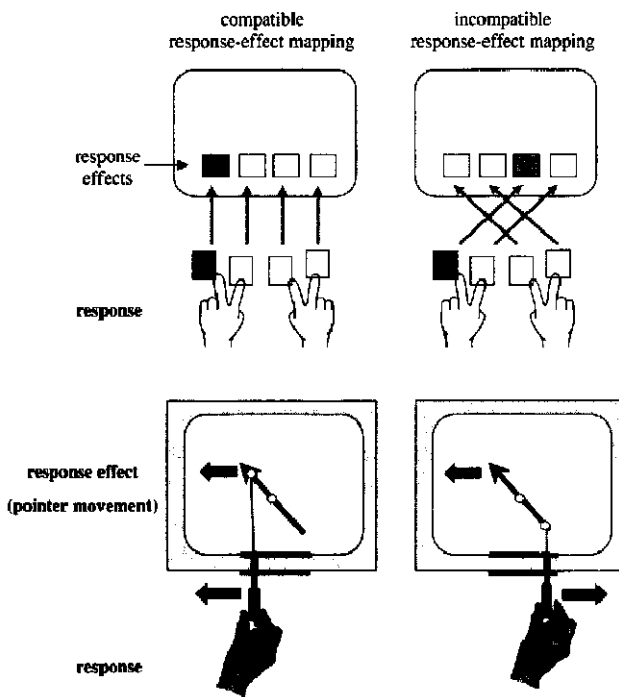


Fig. 3 Examples of compatible and incompatible response-effect conditions. Participants respond faster when the key presses switch on spatially compatible rather than spatially incompatible lamps (Kunde 2001). Likewise, participants respond faster when their hand and a to-be-manipulated tip of a pointer move in corresponding rather than non-corresponding directions (Kunde et al. 2007)

nature of action-mediating effect codes have been addressed. In the following, we discuss two of them. First, can these anticipatory effect codes be qualified as being percept-like, or analogue, in the sense of an “image” as James (1890) has originally assumed? Some supporting evidence comes from the production of effects with variable duration. It takes longer to initiate a movement that produces a long, rather than a short, auditory effect (Kiesel and Hoffmann 2004; Kunde 2003). Long-lasting effects are trivially more extended in time and thus the creation of a percept-like representation of such an effect should take more time than the creation of the representation of a short effect. Conversely, there is no reason to assume that the physical duration of action effects should play a role, when the duration is stored in an abstract form. Further evidence for an analogue nature of action-generating effect representations comes from a study by Koch and Kunde (2002). Participants had to vocalize a color word (e.g., the word, blue). In different sessions, these vocal responses produced as an action effect the presentation of either a compatible color word (e.g., BLUE) or an incompatible color word (e.g., GREEN) on a computer screen. In one group of participants, the physical color of these effect words was always neutral (white), whereas in another group the effect

words were always presented in the color that they denoted on the verbal level (e.g., the word GREEN in green color). Interestingly, the ensuing response-effect compatibility effect was almost twice as large in the group with colored words than in the group with white words. This suggests that the physical color of the words was spontaneously coded and used for response production.

The second issue concerns the capacity-limitations imposed on effect anticipation. Our ability to plan more than one action at a time is severely limited. One well-known demonstration of this limitation is the psychological refractory period (PRP) effect. The selection of a motor response is delayed the more it overlaps in time with the planning of another action. It would support the ideo-motor approach, if these limitations were shaped somehow by the consequences of the to-be-produced action effects. Again, the available evidence is confirmatory. It is easier to “switch” from an initially prepared action to an alternative action when the initially prepared and the finally to-be-performed action produce identical rather than different sensory effects (Kunde et al. 2002). Also, when the left and right hand have to independently manipulate two objects at the same time (such as placing two bricks in a certain orientation), this appears to be much easier when the intended object manipulations of the two hands are the same rather than when they are different (Kunde and Weigelt 2005). And finally, recent evidence suggests that the anticipation of effect codes coincides with a processing “stage” that information-processing theories denote as response selection stage (Paelecke and Kunde 2007). This nicely underscores that even apparently stimulus-driven responses in a choice reaction task are actually goal-oriented actions that require the activation of anticipatory effect codes.

To wrap up, there is evidence to show that anticipatory effect codes (1) become activated during action production and (2) that such codes have the power to affect the speed with which motor actions are generated. In most of the reviewed studies, these action effects were task-irrelevant in the sense that the task could have been carried out without taking these effects into account. Still, they did impact performance, which leads us to conclude that the anticipation of these effects is an insurmountable component of action production, presumably because codes of these effects serve as mental cues for the selection of appropriate motor patterns.

Anticipatory stimulus codes

Although the evidence reviewed so far suggests that it is indispensable to anticipate action effects to act intentionally, it becomes clear on reflection that this cannot be the

whole story. Obviously, to behave adaptive in everyday life as well as in a laboratory task, one has to take into account the environmental conditions in which the actor is situated. Specifically, to successfully perform a specific goal-oriented action, appropriate context conditions must be met. For example, to open a door, a doorhandle has to be present, or to turn on a radio, a corresponding power button has to be found, or to correctly respond in a choice reaction experiment, a certain stimulus must be awaited. Thus, a goal-oriented action requires a representation of adequate start conditions. These representations are not anticipatory in the sense that they refer to clearly predictable events. In fact, we might sometimes have to actively search for these start conditions, for example when we look for the light switch in an unfamiliar room to turn on the light. Still, it is fair to term such representations of start conditions anticipatory, because they have to exist before appropriate context conditions are encountered.

Interestingly, similar to the case of anticipatory *effect* codes, the idea of anticipatory *stimulus* codes has already been expressed in some detail by authors of the early days of psychology. Among them was Exner (1879), who construed the execution of a planned action as a “prepared reflex” (Hommel 2000). The actor prepares himself/herself to act in a specific way when a certain event is encountered. This preparation, the construction of an “if-then” rule, normally occurs before the relevant stimulus actually arrives. A stimulus that matches the “if part” of the rule starts the action off, which then unfolds in a more or less unsupervised manner. Similar concepts have been described later such as “Bezugsvorstellungen” (Ach 1905), implementation intentions (Gollwitzer 1999), start anticipations (Hoffmann 1993) or action plans (Neumann and Klotz 1994). However these concepts are termed; they all ascribe to stimuli an entirely different role than information processing theory does. Stimulus representations are not the starting point of information processing, but the endpoint of preparatory processes, which begin with the action goal (Fig. 2). In other words, a stimulus is an intentionally prepared trigger of a goal-oriented action.

There is a good deal of evidence for such action trigger representations, which covers behaviors as immediate as a response in a laboratory task to behaviors as delayed as the start of sport activities in a forthcoming holiday (cf. Gollwitzer 1999). In fact, several well-known experimental phenomena might be reinterpreted in terms of action triggers. One example is the Stroop-task where participants have to name the ink color in which a certain color word is written (Stroop 1935). Naming is much more difficult when the physical color does not match the color denoted by the word (e.g., the word RED in green color) than when the word and physical color match (e.g., the word RED in red color). Apparently, it is difficult to refrain from reading the

word, when asked to verbalize a color name. Interestingly, Stroop interference seems to be much smaller when the requested action is not to name the word but to press a corresponding response button (cf. MacLeaod 1991 for review). This makes sense from the perspective of anticipatory trigger conditions. A written color word is normally an adequate trigger stimulus to verbalize a color word (as it is the case in reading). Therefore, written color words are hard to ignore when the response is naming. By contrast, a written word does not that frequently serve to trigger a key press action and thus interferes less with key pressing than with naming.

Given the importance of appropriate action triggers, it would be good that once the actor is prepared to carry out a certain goal-oriented action, the action is emitted instantaneously as soon as a proper contextual condition is met. Otherwise, the good opportunity might be missed. Indeed, appropriate action triggers seem to prompt the prepared action before or even without becoming aware of the trigger event itself (Fig. 4).

This unconscious action triggering is illustrated well by masked response priming. In masked priming experiments, participants are asked to execute a certain motor action when a certain stimulus, let us say, a digit smaller than five is presented and another action when a digit larger than five comes up. Interestingly, the action is emitted more quickly when the target digit is preceded by a masked prime that is assigned to the same motor action (e.g., 2 → 4), rather than when the target is preceded by a prime assigned to the alternative action (e.g., 7 → 4). Brain imaging studies have shown that the prime presentation leads to measurable brain activation up to motor areas (Dehaene et al. 1998). Apparently, the system starts to execute the corresponding action as soon as an appropriate trigger event (a digit of certain numerical size) occurs, be it consciously accessible or not.

Masked priming has revealed a couple of interesting aspects of such action trigger representations. First, there is an asymmetric role of consciousness regarding the creation and operation of action trigger representations. The creation of trigger representations is shaped by conscious experience, whereas their operation is not. When the set of consciously experienced target digits is confined to a certain magnitude range (e.g., from 3 to 7), only primes from this magnitude range work as unconscious triggers, whereas stimuli out of this range do not (Kunde et al. 2003). By contrast, the structure of the unconscious prime stimuli has no influence on the way action trigger representations are created and the way stimuli are processed (Merikle and Joorden 1997).

Second, action triggers are particularly effective when they relate the simplest available features, an observation anticipated by Ach (1905) in his “law of specific deter-

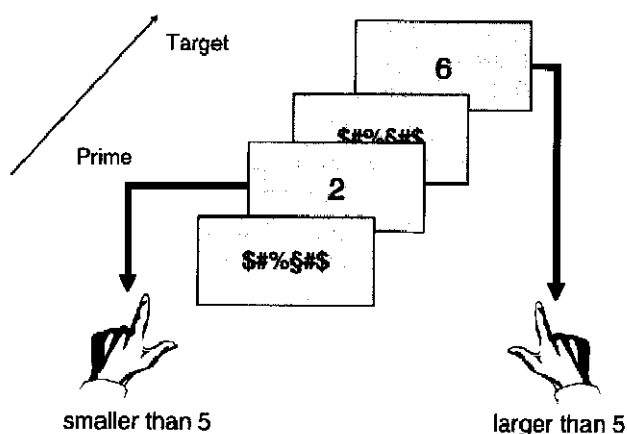


Fig. 4 Masked priming experiment for the study of unconscious operation of action triggers

mination.” Normally, quickly available perceptual features are preferred over “semantic” features that afford access to long-term memory. To give an example, when participants have no reason to suspect that other stimuli than digits are presented, subliminal number words exert no priming, although they convey the same semantic information as digits (Kunde et al. 2005; but see Van Opstal et al. 2005). Yet, when digits and number words are presented as conscious targets, both types of stimuli activate responses unconsciously. Or, when all consciously presented digits are presented in a normal upright orientation, tilted digits exert no priming, but they do so when targets are tilted as well (Elsner et al. 2006). This dominant role of perceptual features as action triggers, independent of the official task instructions say, puts a note of cautiousness on early, enthusiastic reports of unconscious semantic priming (Dehaene et al. 1998). It becomes more and more clear that, although action triggers might relate to semantic features as well, it is much harder to obtain clear evidence for unconscious access to meaning than previously believed (Kiesel et al. 2006; Klauer et al. 2006).

Finally, the participants are able to maintain action trigger representations for two tasks at a time, at least when switching between these tasks is likely and unpredictable. Kiesel et al. (2007) asked participants to perform two tasks, classifying digits as smaller or larger than five and classifying letters as vowels or consonants. Participants had to perform these tasks in an unpredictable order, but they were cued which task was requested in the next trial. In each trial, the prime belonged to the currently irrelevant task. Thus, when digits were classified, the prime was a letter, and when letters were classified, the prime was a digit. Still, primes even from the currently irrelevant task caused response priming, which indicates that the trigger codes for this irrelevant task remain active. The priming effects from irrelevant stimuli were present in task repeti-

tion trials as well as in task switch trials, which rules out that the activation of irrelevant trigger codes was a mere aftereffect of having performed the irrelevant task just a moment before.

To summarize, there is a good deal of evidence showing that humans create mental representations of start conditions that prompt the execution of prepared actions when appropriate conditions are met. After such start conditions have been set up, the behavior might not be too different from that of a frog catching a passing fly. Yet, the important difference is that trigger conditions are more or less innate in the frog, whereas they change flexibly according to current task demands in humans. Important questions for future research are how these action trigger conditions are established (intentionally or implicitly), what level of representation they address (low-level perceptual or semantic), and whether there are any drawbacks in preparing for an action this way, such as a higher behavioral rigidity.

Conclusions

When pondering over the role of anticipation in human cognition, barely anyone would disagree that anticipation is useful. What we have tried here was to illustrate that anticipation is much more deeply incorporated in the cognitive system than just being a useful but otherwise dispensable ingredient. Acting without anticipating is impossible. This applies to the efferent side of action. The ideomotor-approach, which describes this side of the coin, does not only assume that the anticipation of action effects is somehow helpful in guiding our actions, but it also literally assumes that actions are planned in terms of such effects. In other words, action generation is goal anticipation, and this is so even for such simply and apparently stimulus-driven actions as choice reactions. We have seen that the creation of anticipatory goal codes might be linked to conscious experience, but the activation of appropriate body movements is not (Kunde 2004). A similar point applies to the afferent side of the action system. We may perceive this and that; but stimuli have a more direct and immediate impact on behavior when they have been anticipated as an adequate trigger condition for goal-oriented action. Again, the creation of certain trigger conditions might be consciousness mediated, but the activation of the corresponding motor actions is not (Kunde et al. 2003). Shortly, thus, action generation affords (effect) anticipation and perception affords (stimulus) anticipation as well. This short conclusion might be hopelessly oversimplified, but it stresses the role of processes that precede stimulation and eventually determine our action. To study these anticipatory processes is cer-

tainly a worthwhile project where progress can confidently be anticipated.

Acknowledgments We thank Michael Ziessler for the helpful comments on an earlier version of this paper. This work was supported by a grant of the German Research Foundation (DFG) KU 1964.

References

- Ach N (1905) Über die Willenstätigkeit und das Denken. Vandenhoeck & Ruprecht, Göttingen
- Adams JA (1971) A closed-loop theory of motor learning. *J Mot Behav* 3:111–149
- Brass M, Bekkering H, Prinz W (2001) Movement observation affects movement execution in a simple response task. *Acta Psychol* 106:3–22
- Braver TS, Barch DM (2006) Extracting core components of cognitive control. *Trends Cogn Sci* 10:529–532
- Butz MV, Hoffmann J (2002) Anticipations control behavior: animal behavior in an anticipatory learning classifier system. *Adapt Behav* 10:75–96
- Dehaene S, Naccache L, Le Clec HG, Koechlin E, Mueller M, Dehaene-Lambertz G, van de Moortele PF, Le Bihan D (1998) Imaging unconscious semantic priming. *Nature* 395:597–600
- Desmurget MP, Grafton S (2000) Forward modeling allows feedback control for fast reaching movements. *Trends Cogn Sci* 4:324–431
- Donders FV (1868/1969) On the speed of mental processes. *Acta Psychol* 30:412–431
- Dosenbach NU, Visscher KM, Palmer ED, Miezin FM, Wenger KK, Kang HC, Burgund ED, Grimes AL, Schlaggar BL, Petersen SE (2006) A core system for the implementation of task sets. *Neuron* 50:799–812
- Drost UC, Rieger M, Braß M, Gunter TC, Prinz W (2005) Action-effect coupling in pianists. *Psychol Res* 69:233–241
- Elsner B, Hommel B (2001) Effect anticipation and action control. *J Exp Psychol Hum Percept Perform* 27:229–240
- Elsner K, Kunde W, Kiesel A (2006) Limited transfer of subliminal response priming to novel stimulus appearances and identities (Manuscript submitted)
- Exner S (1879) Physiologie der Grosshirnrinde. In: Herrmann L (ed) *Handbuch der Physiologie*, 2. Band, 2. Theil. Leipzig Vogel, pp 189–350
- Greenwald AG (1970) Sensory feedback mechanisms in performance control: with special reference to the ideo-motor mechanism. *Psychol Rev* 77(2):73–99
- Gollwitzer PM (1999) Implementation intentions: strong effects of simple plans. *Am Psychol* 54:493–503
- Harleß E (1861) Der apparat des willens. *Z Philos philos Krit* 38:50–73
- Heyes CM (2001) Causes and consequences of imitation. *Trends Cogn Sci* 5:253–261
- Hoffmann J (1993) Vorhersage und Erkenntnis. Hogrefe, Göttingen
- Hoffmann J (2003) Anticipatory behavioral control. In: Butz M, Sigaud O, Gerard P (eds) *Anticipatory behavior in adaptive learning systems*. Springer, Heidelberg, pp 44–65
- Hommel B (1996) The cognitive representation of action: automatic integration of perceived action effects. *Psychol Res* 59:176–186
- Hommel B (2000) The prepared reflex: automaticity and control in stimulus-response translation. In: Monsell S, Driver L (eds) *Control of cognitive processes: attention and performance XVIII*. MIT Press, Cambridge, pp 247–273
- Hommel B, Müsseler J, Aschersleben G, Prinz W (2001) The theory of event coding (TEC): a framework for perception and action planning. *Behav Brain Sci* 24:849–878
- James W (1890/1981) *The principles of psychology*. Harvard University Press, Cambridge (original work published 1890)
- Kiesel A, Hoffmann J (2004) Variable action effects: response control by context-specific effect anticipations. *Psychol Res* 68:155–162
- Kiesel A, Kunde W, Pohl C, Hoffmann J (2006) Priming from novel masked stimuli depends on target set size. *Adv Cogn Psychol* 2:37–45
- Kiesel A, Kunde W, Hoffmann J (2007) Unconscious priming according to multiple S-R rules. *Cognition* (in press)
- Klauer KC, Eder A, Greenwald AG, Abrams RL (2006) Priming of semantic classification by novel subliminal prime words. *Conscious Cogn* 16(1):63–83
- Koch I, Kunde W (2002) Verbal response-effect compatibility. *Mem Cogn* 30:1297–1303
- Kunde W (2001) Response-effect compatibility in manual choice reaction tasks. *J Exp Psychol Hum Percept Perform* 27:387–394
- Kunde W (2003) Temporal response-effect compatibility. *Psychol Res* 67:153–159
- Kunde W (2004) Response priming by supraliminal and subliminal action effects. *Psychol Res* 68:91–96
- Kunde W, Weigelt M (2005) Goal congruency in bimanual object manipulation. *J Exp Psychol Hum Percept Perform* 31:145–156
- Kunde W, Hoffmann J, Zellmann P (2002) The impact of anticipated action effects on action planning. *Acta Psychol* 109:137–155
- Kunde W, Kiesel A, Hoffmann J (2003) Conscious control over the content of unconscious cognition. *Cognition* 88(2):223–242
- Kunde W, Koch I, Hoffmann J (2004) Anticipated action effects affect the selection, initiation, and execution of actions. *Q J Exp Psychol A* 57:87–106
- Kunde W, Kiesel A, Hoffmann J (2005) On the masking and disclosure of unconscious elaborate processing. A reply to van Opstal, Reynvoet, and Verguts. *Cognition* 97:99–105
- Kunde W, Müsseler J, Heuer H (2007) Spatial compatibility effects with tool use. *Hum Factors* (in press)
- Lotze H (1852) *Medicinische psychologie oder physiologie der seele*. E. J. Bonset, Amsterdam
- MacLeod C (1991) Half a century of research on the Stroop effect: an integrative review. *Psychol Bull* 109:163–203
- Meltzoff AN, Moore MK (1977) Imitation of facial and manual gestures by human neonates. *Science* 198:75–78
- Merikle PM, Joorden s (1997) Parallels between Perception without Attention and Perception without awareness. *Conscious Cogn* 6:219–236
- Monsell S (1996) Control of mental processes. In: Bruce V (ed) *Unresolved mysteries of the mind*. Erlbaum, Hove, pp 93–148
- Monsell S (2003) Task switching. *Trends Cogn Sci* 7:134–140
- Neisser U (1967) *Cognitive Psychology*. Prentice-Hall, Englewood
- Neumann O, Klotz W (1994) Motor responses to nonreportable, masked stimuli: Where is the limit of direct parameter specification? In: Umiltà C, Moscovitch M (eds) *Attention and performance XV*. Conscious and nonconscious information processing. MIT Press, Cambridge, pp 123–150
- Paelecke M, Kunde W (2007) Action-effect codes in and before the central bottleneck: evidence from the PRP paradigm. *J Exp Psychol Hum Percept Perform* (in press)
- Prinz W (1987) Ideomotor action. In: Heuer H, Sanders AF (eds) *Perspectives on perception and action*. Erlbaum, Hillsdale, pp 47–76
- Prinz W (1997) Perception and action planning. *Eur J Cogn Psychol* 9:129–154
- Prinz W (1998) Die Reaktion als Willenshandlung. *Psychol Rundsch* 49:10–20

- Sanders A (1980) Stage analysis of reaction processes. In: Stelmach GE, Requin J (eds) *Tutorials in motor behavior*. Amsterdam: North Holland, pp 331–354
- Sanders AF (1998) *Elements of human performance: Reaction processes and attention in human skill*. Erlbaum, Mahwah
- Sternberg S (1969) The discovery of processing stages: extensions of Donders' method. *Acta Psychol* 30:276–315
- Stürmer B, Aschersleben G, Prinz W (2000) Correspondence effects with manual gestures and postures: a study of imitation. *J Exp Psychol Hum Percept Perform* 26:1746–1759
- Stock A, Stock C (2004) A short history of ideo-motor action. *Psychol Res* 68:176–188
- Stroop JR (1935) Studies of interference in serial verbal reactions. *J Exp Psychol* 18:643–662
- Tinbergen (1951) *The study of instinct*. Oxford University press, New York
- Rieger M (2004) Automatic keypress activation in skilled typing. *J Exp Psychol Hum Percept Perform* 30:555–565
- Van Opstal F, Reynvoet B, Verguts T (2005) Unconscious semantic categorization and mask interactions: an elaborate response to Kunde et al. (2005). *Cognition* 97:107–113
- Wolpert DM, Gharamani Z, Flanagan JR (2002) Perspectives and problems in motor learning. *Trends Cogn Sci* 5:487–494